7 Conclusions and Future Work

7.1 Summary

I presented a novel approach for system design—Fuzzy CoCo—based on fuzzy logic and coevolutionary computation, which is conducive to explaining human decisions. My algorithm has been able to find accurate and interpretable systems for hard, real-world problems. The analysis of Fuzzy CoCo and of the systems it produced shows, among other features, the consistency of the results. I also proposed two extensions to the method, which deserve further exploration.

Evolutionary fuzzy modeling—i.e., the design of fuzzy inference systems using evolutionary algorithms—constitutes the methodological base of my work. In Chapter 2 I studied extant evolutionary fuzzy modeling approaches and some criteria and considerations involved in this task. I emphasized an aspect usually neglected in most approaches: interpretability. In particular, I presented some strategies to satisfy semantic and syntactic criteria that reinforce the interpretability of the systems produced. To illustrate these concepts, I applied a basic fuzzy-genetic approach to solve a medical diagnostic problem: the WBCD problem. The systems obtained were the best explanatory systems presented at the time for this problem.

The aforementioned study brought to the fore some limitations of evolutionary fuzzy modeling, but, at the same time, it provided clues on how to overcome them. Based on these clues, I proposed the use of cooperative coevolution to surmount the problem of dealing with different types of parameters in the same genome. This is the origin of Fuzzy CoCo, presented in detail in Chapter 3, together with a simple application example: the Iris classification problem. The systems obtained for this problem surpassed previous fuzzy modeling results.

Fuzzy CoCo was then used in Chapter 4 to model the decision processes involved in two breast-cancer diagnostic problems: the WBCD problem and the Catalonia mammography interpretation problem. For the WBCD problem, Fuzzy CoCo produced markedly better results using less or similar computational resources than the fuzzy-genetic approach. For the Catalonia problem, an evolved system was embedded within a web-based tool—called COBRA—for aiding radiologists in mammography interpretation.

In order to attain a deeper understanding of Fuzzy CoCo, I performed in Chapter 5 several analyses regarding the performance of the methodology and of the systems it produces. These analyses involve aspects like the application of the method,
the effects that some parameters have on performance, the consistency and the quality of the systems designed using Fuzzy CoCo, as well as their local generality. Finally, I proposed two extensions: Island Fuzzy CoCo and Incremental Fuzzy CoCo, which together with the original CoCo constitute a family of coevolutionary fuzzy modeling techniques. The extensions are intended to guide the choice of an adequate number of rules for a given problem—a critical, hard-to-define parameter of Fuzzy CoCo. The encouraging preliminary results obtained with these extensions motivate further investigation.

7.2 Original Contributions

To the best of my knowledge, this is the first work to analyze and develop in-depth the concept of coevolutionary fuzzy modeling. While this in itself constitutes an original achievement, it is not the only contribution of the present research to the state of the art. In this section, I will outline the most interesting original contributions.

– In Section 2.1, which studies the fuzzy modeling problem, I proposed a novel classification of the parameters of fuzzy systems into four classes: logic, structural, connective, and operational. This classification was used to decompose the fuzzy modeling problem and to analyze how existing modeling techniques dealt with it. These analyses provided some key ideas, important to the conception of Fuzzy CoCo. In particular, they served to show that most of the time the fuzzy modeling problem reduces to the design of connective and operational parameters, which are very different in nature. This fact led to the idea of applying cooperative coevolution.

– The interpretability considerations presented in Section 2.3 contain several original elements. First, observing that most of the interpretability criteria presented in the literature were mainly oriented toward constraining the definition of membership functions, I grouped them under the label semantic criteria, as they affect the coherence of the linguistic concepts. Then, I identified and proposed some other criteria regarding the rule base, which are called syntactic criteria, as they affect the (causal) connection between linguistic concepts. Finally, I proposed a set of modeling strategies that, when applied, should reinforce the linguistic integrity—both semantic and syntactic—of the fuzzy systems produced. Note that these considerations are valid for any fuzzy modeling technique.

– Chapter 3 introduced Fuzzy CoCo, a novel cooperative coevolutionary approach to fuzzy modeling. The idea of applying cooperative coevolution arose from the observation that the fuzzy modeling problem should be decomposed into (at least) two separated but related search processes: one for connective, the other for operational parameters. Cooperative coevolution succeeds in overcoming some limitations exhibited by standard evolutionary fuzzy modeling: stagnation, convergence to local optima, and computational costliness. Besides performance improvement, Fuzzy CoCo was designed with interpretability being a prime goal.